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ALTITUDE ACCLIMATIZATION ATTENUATES PLASMA AMMONIA  
ACCUMULATION DURING SUBMAXIMAL EXERCISE(U) ARMY  
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# Altitude acclimatization attenuates plasma ammonia accumulation during submaximal exercise

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YOUNG, PATRICIA M., PAUL B. ROCK, CHARLES S. FULCO, LAURIE A. TRAD, VINCENT A. FORTE, JR., AND ALLEN CYMERMAN. Altitude acclimatization attenuates plasma ammonia accumulation during submaximal exercise. J. Appl. Physiol. 63(2): 758-764, 1987. This study examined the effects of acclimatization to 4,300 m altitude on changes in plasma ammonia concentrations with 30 min of submaximal (75% maximal  $\dot{V}O_2$  uptake ( $\dot{V}O_{2\max}$ ))-cycle exercise. Human test subjects were divided into a sedentary ( $n = 6$ ) and active group ( $n = 5$ ). Maximal uptake ( $\dot{V}O_{2\max}$ ) was determined at sea level and at high altitude (HA; 4,300 m) after acute ( $t < 24$  h) and chronic ( $t = 13$  days) exposure. The  $\dot{V}O_{2\max}$  of both groups decreased 32% with acute HA when compared with sea level. In the sedentary group,  $\dot{V}O_{2\max}$  decreased an additional 16% after 13 days of continuous residence at 4,300 m, whereas  $\dot{V}O_{2\max}$  in the active group showed no further change. In both sedentary and active subjects, plasma ammonia concentrations were increased ( $P < 0.05$ ) over resting levels immediately after submaximal exercise at sea level as well as during acute HA exposure. With chronic HA exposure, the active group showed no increase in plasma ammonia immediately after submaximal exercise, whereas the postexercise ammonia in the sedentary group was elevated but to a lesser extent than at sea level or with acute HA exposure. Thus postexercise plasma ammonia concentration was decreased with altitude acclimatization when compared with ammonia concentrations following exercise performed at the same relative intensity at sea level or acute HA. This decrease in ammonia accumulation may contribute to enhanced endurance performance and altered substrate utilization with exercise following acclimatization to altitude.

plasma lactate; insulin; glucose; maximal oxygen uptake

DURING THE FIRST 3 wk of altitude acclimatization, a dramatic increase in endurance capacity for submaximal exercise has been reported (16). The mechanism of this adaptation has not been identified. However, it has been shown that after 18 days of residence at 4,300 m altitude, alterations occur in energy substrate utilization during exercise. After this period of acclimatization, postexercise blood lactate levels were decreased and muscle glycogen utilization was reduced; increased utilization of free fatty acid appeared to account for the "glycogen sparing" (28). Similar changes in metabolism have been observed as a result of long-term endurance training (18, 20). However, metabolic adaptations to endurance training are associated with increased activity of oxidative enzymes (13), and changes in human skeletal muscle

enzyme activities were not observed with short-term altitude acclimatization (29). Thus an alternative mechanism for the reduction in glycogen utilization with altitude acclimatization must exist.

Ammonia is a metabolite produced by exercising muscle, and reductions in postexercise ammonia levels have been observed in endurance-trained rats (5). Ammonia is not a direct metabolite of the glycolytic pathway but is produced by the purine nucleotide cycle (15). During the operation of the PNC, ammonia is produced as a byproduct of reaction in which adenosine monophosphate (AMP) is converted to inosine monophosphate. In vitro experiments have shown that elevated intracellular ammonia levels increase the rate of glycolysis by activation of phosphofructokinase (15) and lead ultimately to an increase in lactate levels by inhibition of pyruvate carboxylase and pyruvate dehydrogenase (8, 9, 27). Plasma ammonia and lactate levels are closely correlated in humans exercising at sea level (26), but the effect of acute and chronic high-altitude exposure on ammonia accumulation during exercise has not been reported. Changes in ammonia metabolism during exercise at high altitude may be related to the alterations in energy substrate utilization associated with altitude acclimatization.

The purpose of this investigation was to test the hypothesis that altitude acclimatization would result in decreased ammonia accumulation during submaximal exercise. A decrease in ammonia levels could lead ultimately to a reduction in glycolytic activity, thereby accounting for decreased glycogen breakdown and decreased lactate accumulation during exercise. To separate the effects of altered physical activity during the altitude sojourn from the effects of altitude acclimatization, the responses of a sedentary group were compared with a group engaged in a physical exercise regimen.

## METHODS

After being informed of the nature and requirements of the study, 12 healthy male soldiers ( $20 \pm 2$  yr) voluntarily consented to serve as test subjects. One subject left the study during the acute altitude phase. All subjects were sea-level natives who had not been exposed to an altitude  $> 1,500$  m for at least 6 mo before the study. The subjects had participated in typical US Army physical training before the study, but none was exceptionally

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well trained. Before experimental testing began, a preliminary determination of each subject's maximal  $\dot{V}O_2$  uptake ( $\dot{V}O_{2\max}$ ) during both rowing and cycling was performed to enable the subjects to be matched in pairs of similar aerobic fitness. One member of the pair was assigned randomly to the sedentary group, the other to the active group.

The study consisted of a 21-day sea-level (50 m) phase completed in Natick, MA, and a 14-day altitude phase where subjects resided on the summit of Pikes Peak, CO (4,300 m). Daily caloric intake during the sea-level phase averaged 2,750 and 1,750 kcal/day during the altitude phase with 15% of the total kilocalories from fat; 20%, protein; and 65%, carbohydrate. During the study, there was no difference in average weight loss ( $4.73 \pm 0.62$  kg) between groups. During both phases, the active group ( $n = 5$ ) exercised twice daily for 20 min on a rowing ergometer (Concept II, Morrisville, VT) at 75% of the altitude-specific rowing  $\dot{V}O_{2\max}$ . The sedentary group ( $n = 6$ ) did not perform any physical exercise other than that associated with normal living activities.

During the final 6 days of the sea-level phase, the cycling  $\dot{V}O_{2\max}$  of the subjects was measured once under ambient pressure (50 m) and again at a simulated altitude of 4,300 m [acute high altitude (HA)] to allow comparison with the  $\dot{V}O_{2\max}$  subsequently measured on day 13 of continual residence at 4,300 m on Pikes Peak (chronic HA). In addition, the subjects performed three 30-min submaximal cycling exercise tests to study plasma metabolite responses during continuous steady-state exercise. Submaximal testing was performed once during the sea-level phase (day 19), during the first 24 h at Pikes Peak (acute HA), and on day 14 of continuous residence at Pikes Peak (chronic HA). All three submaximal tests consisted of 30 min of cycling at 75% of the environmental specific  $\dot{V}O_{2\max}$ .

The  $\dot{V}O_{2\max}$  determinations were performed using a progressive intensity continuous exercise protocol. The criterion used to define  $\dot{V}O_{2\max}$  was an increase of  $<150$  ml/min per 25-W increase in exercise intensity. Cycling exercise was performed on an electronically braked cycle ergometer (Collins, Braintree, MA). All cycling was performed at 60 rpm. Subjects were paced with an electronic metronome while an observer counted pedal revolutions to ensure uniform exercise intensity.

Respiratory gas exchange and ventilation during exercise were measured using a semiautomated system. The subjects breathed through a triple J valve connected to an Applied Electrochemistry 3A fuel cell (Sunnyvale, CA) on-line with a Beckman LB-2 infrared analyzer (Anaheim, CA). Expired gas volumes were measured using a pneumotach (model 47304A, Hewlett-Packard, Lexington, MA). The data were collected, stored, and analyzed with a Digital Equipment Corporation MNC11-AA computer (Maynard, MA) with the use of a software package developed for this purpose. Minute ventilation ( $\dot{V}_E$ ) converted to BTPS,  $O_2$  consumption ( $\dot{V}O_2$ ) and  $CO_2$  production converted to STPD, and respiratory exchange ratio (R) and heart rate were averaged and printed each minute during exercise.

Before subjects arose on the morning of each submax-

imal exercise test, venous blood was collected from fasting subjects in ethylenediaminetetraacetic acid from a catheter placed in the median basilic vein. Blood was also sampled immediately before and after submaximal exercise and after a 30-min and 60-min recovery period. Plasma was separated by centrifugation and analyzed for lactate concentration using an automated analyzer (model 23L, Yellow Springs Instrument, Yellow Springs, OH) and ammonia levels using an enzymatic kit (Sigma Chemical, St. Louis, MO) within 2 h of collection. The remaining samples were stored in liquid nitrogen ( $-196^\circ\text{C}$ ) until analyzed. All samples from one subject were analyzed in the same assay to avoid interassay variance. Plasma glucose concentration was determined using an automated analyzer (Beckman, Palo Alto, CA). Plasma insulin levels were determined by radioimmunoassay (Serono Laboratories, Randolph, MA). Blood urea nitrogen levels were determined by a colorimetric method (Sigma Chemical). Plasma free fatty acid (FFA) levels were determined by a colorimetric method (Nippon Shoji Kaisha, Osaka, Japan), and plasma glycerol levels were determined by an enzymatic kit (Behring Diagnostics, La Jolla, CA).

Data were analyzed using a three-way analysis of variance. A Tukey's critical difference test was used to identify significant differences between means. Statistical significance was accepted at the  $P < 0.05$  level. All data are expressed as means  $\pm$  SE.

## RESULTS

### Maximal Exercise

At sea level, there was no difference between the mean  $\dot{V}O_{2\max}$  of the active group ( $3.82 \pm 0.24$  l/min) and the sedentary group ( $3.84 \pm 0.22$  l/min). Similarly, there was no difference in the mean  $\dot{V}O_{2\max}$  between the active and sedentary group with acute HA exposure averaging  $2.59 \pm 0.09$  and  $2.57 \pm 0.09$  l/min, respectively. This represented a significant ( $P < 0.05$ ) decrease of 32% from values obtained at sea level. After 13 days of residence at 4,300 m, the  $\dot{V}O_{2\max}$  of the active group ( $2.57 \pm 0.07$  l/min) showed no change from acute HA values, whereas the  $\dot{V}O_{2\max}$  of the sedentary group ( $2.17 \pm 0.09$  l/min) decreased by 16% ( $P < 0.05$ ) relative to acute HA.

### Submaximal Exercise

**Exercise  $\dot{V}O_2$ .** During submaximal exercise at sea level,  $\dot{V}O_2$  for the active group ( $2.77 \pm 0.06$  l/min) was significantly higher than during acute HA ( $1.87 \pm 0.07$  l/min) and chronic HA ( $1.77 \pm 0.05$  l/min). There was no difference between submaximal exercise  $\dot{V}O_2$  during acute and chronic HA. For the sedentary group,  $\dot{V}O_2$  at sea level ( $2.78 \pm 0.07$  l/min) was significantly higher than during acute HA ( $1.91 \pm 0.06$  l/min) and chronic HA ( $1.62 \pm 0.05$  l/min). Also,  $\dot{V}O_2$  during acute HA was significantly greater than chronic HA for the sedentary group. Relative exercise intensity ( $\% \dot{V}O_{2\max}$ ) was not different between groups and was the same for all submaximal tests, averaging 73%  $\dot{V}O_{2\max}$  overall.

**Respiratory exchange ratio.** There was no significant difference between the active and sedentary subjects in

the R during exercise at sea level (Table 1). With acute HA, R was higher than sea-level values for both groups, with no significant difference between groups. After 14 days of residence at 4,300 m, the R value for the active group ( $1.03 \pm 0.06$ ) remained the same as with acute HA; in the sedentary group, R ( $1.13 \pm 0.05$ ) increased significantly compared with acute HA. There was no significant difference in  $\dot{V}_E$  during exercise for the active group at sea level, acute HA, or chronic HA. For the sedentary group, there was no significant difference in  $\dot{V}_E$  during exercise at sea level or acute HA; however, with exercise during chronic HA,  $\dot{V}_E$  ( $115.8$  l/min) was significantly higher than sea level. The ventilatory equivalent for  $O_2$  ( $\dot{V}_E/\dot{V}O_2$ ) for the active group at acute HA and chronic HA was increased  $\sim 47\%$  compared with values observed during sea level. For the sedentary group,  $\dot{V}_E/\dot{V}O_2$  was increased 64% at acute HA compared with sea level. During chronic HA,  $\dot{V}_E/\dot{V}O_2$  for the sedentary group increased twofold over values at sea level with a significant (22%) increase over acute HA values.

**Plasma ammonia accumulation.** Plasma ammonia concentrations before and after exercise and recovery are shown in Fig. 1 combined for both groups. There were no significant differences in resting plasma ammonia concentrations between sea level, acute HA, and day 13 of residence at HA. After 30-min submaximal cycling exercise, plasma ammonia was increased to  $102 \pm 5$   $\mu$ M at sea level and  $95 \pm 6$   $\mu$ M at acute HA, representing no difference. After 13 days of residence at 4,300 m, post-exercise levels were  $54 \pm 6$   $\mu$ M, representing a twofold decrease compared with sea level and acute HA values. Plasma ammonia returned to preexercise levels after 30 and 60 min of rest and plasma ammonia during recovery were not different regardless of altitude. Additionally, blood urea nitrogen levels remained unchanged during exercise and recovery (data not shown) at sea level, acute HA, and chronic HA.

The effect of the physical activity regimen on plasma ammonia changes with submaximal exercise and recovery following is shown in Fig. 2. Ammonia levels before exercise at sea level, acute HA, and chronic HA were not different between groups. After exercise, plasma ammonia concentrations in the sedentary group (Fig. 2A) were  $92 \pm 20$  and  $95 \pm 19$   $\mu$ M, and in the exercised group (Fig. 2B)  $106 \pm 15$  and  $83 \pm 18$   $\mu$ M at sea level and acute HA, respectively. Each represents a significant increase over resting values but no significant difference between

groups. During chronic HA, the postexercise plasma ammonia concentration of the sedentary group averaged  $60 \pm 17$   $\mu$ M, which was a significant increase over resting values but significantly lower than observed for this group after exercise at sea level or acute HA. Plasma ammonia levels in the active group were unchanged during exercise at chronic HA. Also, postexercise plasma ammonia levels during chronic HA exposure were significantly lower ( $P < 0.05$ ) in the active group compared with the sedentary group. Following 30 min of recovery, there was no difference in ammonia levels in either group compared with resting values.

**Plasma lactate accumulation.** Plasma lactate concentration before, immediately after, and after 30 min of recovery from submaximal exercise is shown for the sedentary (Fig. 3A) and active (Fig. 3B) groups. Resting plasma lactate concentrations did not differ between groups and were not affected by altitude. For both groups, plasma lactate levels were significantly higher than resting values immediately after exercise at sea level and HA (both acute and chronic). Also, postexercise lactate levels at acute HA were significantly higher than sea-level and chronic HA values. Between groups there were no differences in postexercise lactate values at sea level and acute HA. With chronic HA exposure, postexercise plasma lactate levels of the active group were significantly lower than the sedentary group. After 30 min of recovery at sea level, plasma lactate concentrations in both groups were decreased and were not different from the resting values observed before exercise. After 30 min of recovery at acute and chronic HA, plasma lactate levels in both groups were approximately twofold higher than values at sea level.

**Plasma glucose and insulin concentrations.** The effect of submaximal exercise at sea level and HA on plasma glucose concentration is shown in Fig. 4. There were no significant differences between groups, and the data were pooled for all test subjects. With exercise at sea level, the initial plasma glucose averaged  $4.4 \pm 0.5$  mM, and there was no significant change with exercise or recovery. With acute HA, resting glucose concentration was significantly higher ( $6.8 \pm 0.6$  mM) compared with sea-level values. Plasma glucose concentration decreased during exercise at acute HA to  $4.8 \pm 0.3$  mM but had returned to preexercise levels after 30 min of recovery. After 13 days of residence at 4,300 m, plasma glucose levels were not different from those observed at sea level during rest, exercise, and recovery.

No significant difference in plasma insulin concentration was observed between rest, postexercise, or recovery insulin values at each altitude or between groups for any exercise bout. At sea level, plasma insulin concentration averaged  $8.60 \pm 0.49$   $\mu$ U/ml. During acute HA, plasma insulin concentration averaged  $16.30 \pm 2.01$   $\mu$ U/ml, representing a twofold increase in plasma insulin concentrations compared with sea-level values. After 13 days of residence at 4,300 m, plasma insulin concentration was  $8.90 \pm 1.20$   $\mu$ U/ml, which was not different from sea-level values.

**Plasma free fatty acid: glycerol molar ratio.** The plasma FFA/glycerol molar ratio immediately before and after

TABLE 1. Respiratory exchange and ventilation during submaximal exercise on the cycle ergometer

		R	$\dot{V}_E$	$\dot{V}_E/\dot{V}O_2$
Sedentary	Sea level	$0.84 \pm 0.01$	$86.12 \pm 6.29$	$32.00 \pm 1.29$
	Acute HA	$1.05 \pm 0.01^*$	$103.92 \pm 10.07$	$52.40 \pm 1.91^*$
	Chronic HA	$1.13 \pm 0.051^{*†}$	$115.83 \pm 9.78^*$	$63.74 \pm 3.20^{*†}$
Active	Sea level	$0.84 \pm 0.02$	$97.28 \pm 12.89$	$34.80 \pm 3.10$
	Acute HA	$1.03 \pm 0.01^*$	$99.36 \pm 8.57$	$48.67 \pm 4.55^*$
	Chronic HA	$1.03 \pm 0.06^*$	$95.76 \pm 9.98$	$54.00 \pm 4.55^*$

Values are means  $\pm$  SE of measurements obtained during last 10 min of a 30-min submaximal exercise bout;  $n = 10$ . R, respiratory exchange ratio;  $\dot{V}_E$ , minute ventilation (l/min);  $\dot{V}_E/\dot{V}O_2$ , ventilatory equivalent for  $O_2$ ; HA, high altitude; acute,  $t < 24$  h; chronic,  $t = 13$  days. \*  $P < 0.05$  from sea level.  $† P < 0.05$  from acute HA.

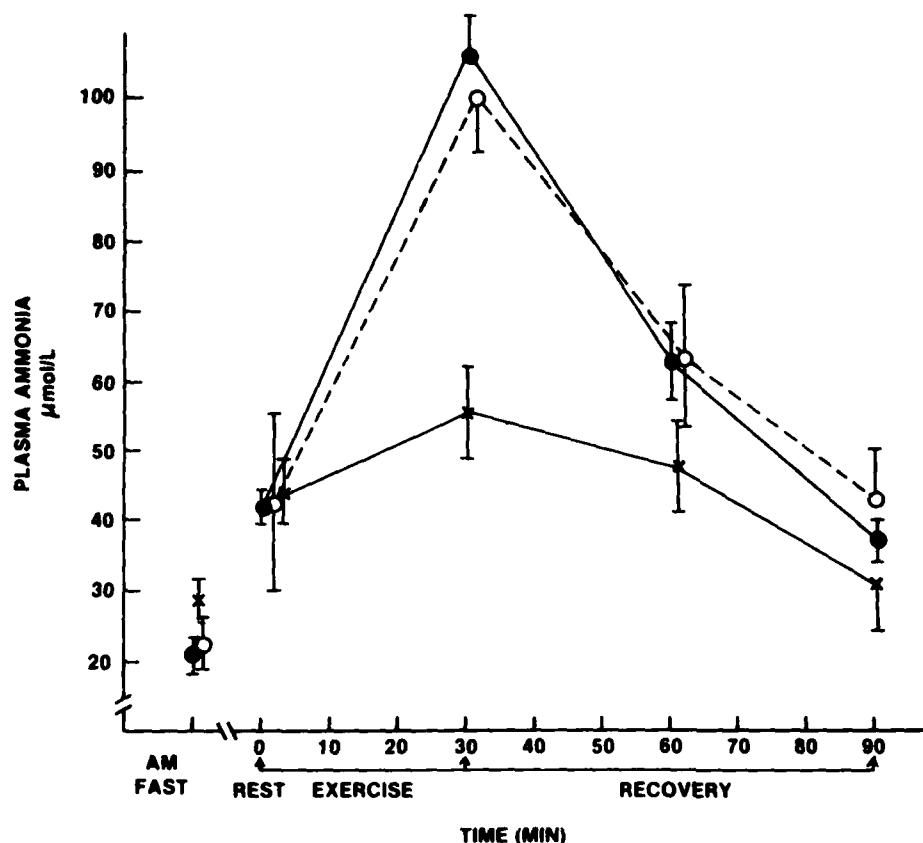


FIG. 1. Effect of submaximal cycling exercise on plasma ammonia concentration. Plasma ammonia levels (means  $\pm$  SE) were measured after an overnight fast before and immediately after exercise and after 30 and 60 min of recovery at sea level (filled circles), acute high altitude (open circles), and chronic high altitude (crosses) for all test subjects. Acute,  $t < 24$  h; chronic,  $t = 13$  days.

submaximal exercise is shown for all subjects in Table 2. There was no difference between resting plasma FFA/glycerol ratio with sea-level and acute HA exposure; however, with chronic HA, resting FFA/glycerol ratio was significantly increased. Exercise at sea level and during acute HA had no significant effect on FFA/glycerol molar ratios; however, at chronic HA, the FFA/glycerol ratio decreased significantly with exercise compared with the resting value.

#### DISCUSSION

In previous investigations of human acclimatization to HA, the effects of altered or decreased physical activity have not been controlled or quantified. Therefore, in the present investigation, subjects were divided into a sedentary and a physically active group. The purpose of the exercise regimen followed by the active group was not to improve aerobic fitness but rather to offset the relatively sedentary lifestyle often assumed by test subjects confined to the summit of Pikes Peak. Rowing ergometry was selected as the mode of activity because it provided exercise for upper and lower extremities but did not train specifically for cycling exercise, the exercise mode used for experimental testing. The subjects in the active group followed the exercise regimen throughout the 21-day sea-level phase in order to habituate them before the altitude phase. Since 3 days before going to high altitude, the mean  $\dot{V}O_{2\max}$  of the two groups were not significantly different, each group began the altitude phase at approx-

imately equal levels of aerobic fitness. Both groups experienced similar decrements in  $\dot{V}O_{2\max}$  with acute high altitude exposure (32% compared with sea level) comparable to other studies at 4,300 m (30). After 13 days at altitude, the sedentary group experienced an additional decrease in  $\dot{V}O_{2\max}$  of 16% compared with acute HA. The subjects participating in the exercise regimen demonstrated no further change in  $\dot{V}O_{2\max}$  between acute HA exposure and day 13 of residence at HA. The additional decrement in  $\dot{V}O_{2\max}$  experienced by the sedentary subjects is similar in magnitude to that reported to occur at sea level with comparable or longer periods of bed rest (20). Although the sedentary subjects did not exercise regularly, they were not confined to bed during this study. It is possible that at extreme altitude a more rapid "detraining" occurs. This possibility should be considered when designing studies requiring continuous residence at high altitude.

This study has demonstrated that, with acclimatization to 4,300 m altitude, postexercise plasma ammonia concentration was decreased compared with exercise bouts during sea level and acute HA that were performed at the same relative intensity. Also, subjects maintaining a constant level of aerobic fitness experienced a greater reduction in postexercise plasma ammonia and lactate accumulation with acclimatization to altitude compared with sedentary subjects. A decreased accumulation of blood ammonia during exercise has also been reported to occur in endurance-trained rats (5). Thus it is possible

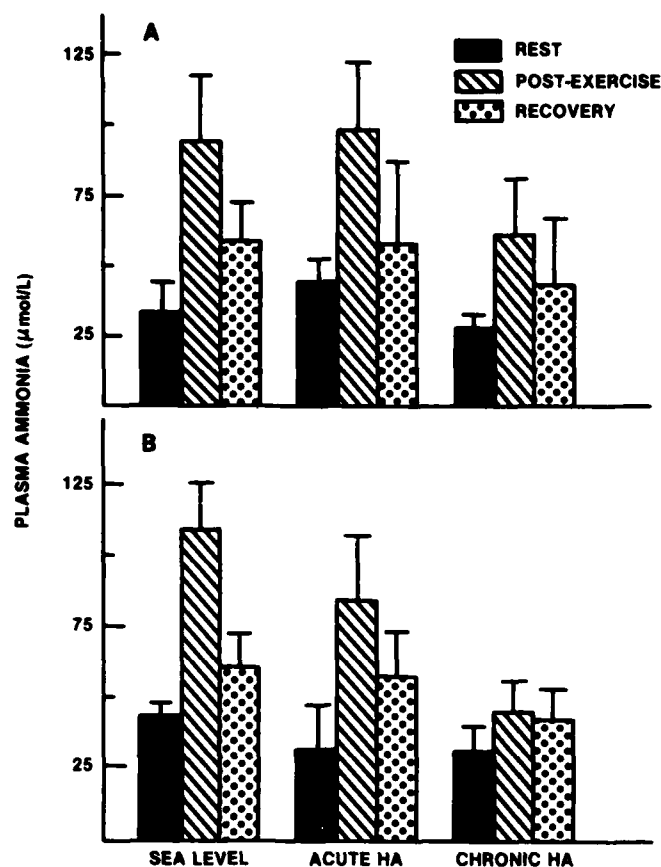


FIG. 2. Plasma ammonia levels at rest, immediately after exercise ( $t < 1$  min), and after 30 min of recovery in sedentary (A,  $n = 6$ ), and exercised (B,  $n = 5$ ) subjects at sea level, acute high altitude (HA;  $t < 24$  h), and chronic high altitude ( $t = 13$  days). Exercise consisted of 30 min of cycling (75% maximal  $\text{O}_2$  uptake). Values are means  $\pm$  SE.

that decreased exercise accumulation of ammonia may account, at least in part, for the increased endurance reported to have occurred in other chronic HA studies (16).

Alterations in ammonia accumulation may effect alterations in energy substrate utilization during exercise. Ammonia and other metabolites of the purine nucleotide cycle modulate the activity of key enzymes in the breakdown of glycogen and oxidation of glucose (2). Ammonia accumulation during exercise would lead to the activation of phosphofructokinase and inhibition of pyruvate dehydrogenase and pyruvate carboxylase. Decreased pyruvate oxidation leads ultimately to increased conversion of pyruvate to lactate. Conversely, decreased levels of ammonia would favor a lower glycolytic rate since less phosphofructokinase would be activated, and pyruvate oxidation would proceed with shunting of metabolites into the trichloroacetic acid cycle rather than lactate accumulation. In addition, since isocitrate dehydrogenase is inhibited by ammonia (14), a decrease in muscle ammonia concentration would lead to enhanced tricarboxylic acid cycle activity. Thus decreased ammonia levels could improve endurance by decreasing lactate accumulation and enhancing tricarboxylic acid cycle activity.

Previous research has demonstrated that with accli-

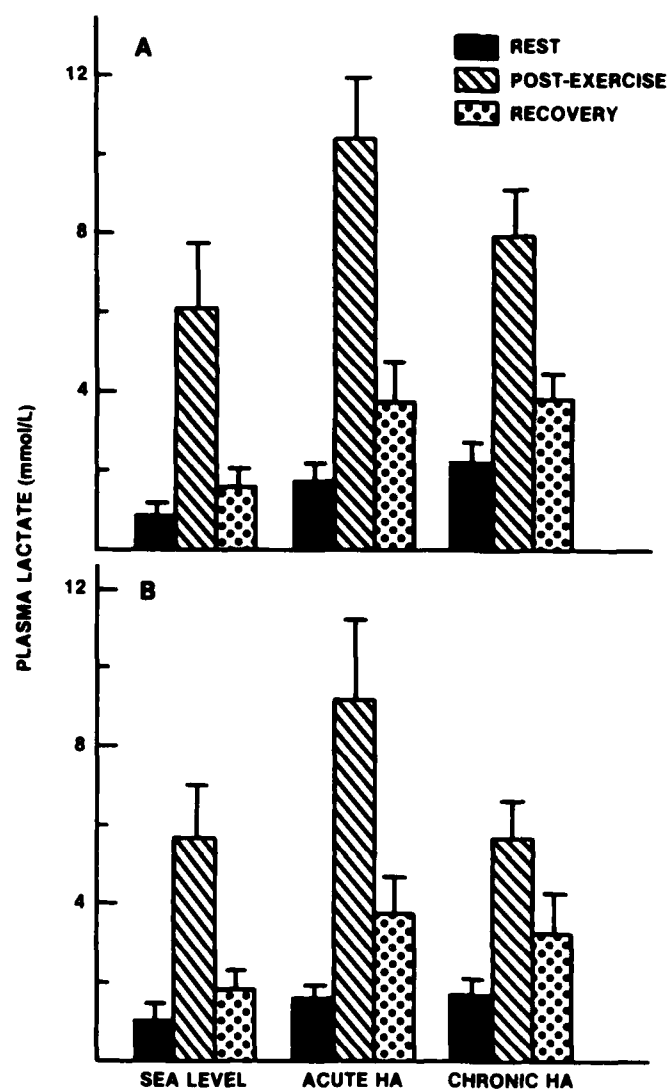


FIG. 3. Plasma lactate levels at rest, immediately after exercise ( $t < 1$  min), and after 30 min of recovery in sedentary (A,  $n = 6$ ) and exercised (B,  $n = 5$ ) subjects at sea level, acute high altitude (HA;  $t < 24$  h), and chronic HA ( $t = 13$  days). See legend to Fig. 2 for additional details.

matization to high altitude, glycogen stores were spared in exercising muscle with an apparent shift to oxidation of FFA for energy (28). In this study, postexercise plasma lactate values were decreased with chronic HA exposure compared with acute HA although exercise was performed at the same intensity. Also, plasma FFA/glycerol ratio was significantly decreased immediately after exercise with chronic HA only, an indication of enhanced FFA uptake and utilization. It is interesting to note that plasma FFA/glycerol ratio was higher before exercise at chronic HA only; thus increased FFA's were available to enter the muscle by mass action at the onset of exercise. Therefore it appears that carbohydrate utilization was diminished and FFA uptake enhanced with acclimatization.

In the present study, plasma glucose concentration was significantly decreased and plasma lactate accumulation was greater immediately after submaximal exer-

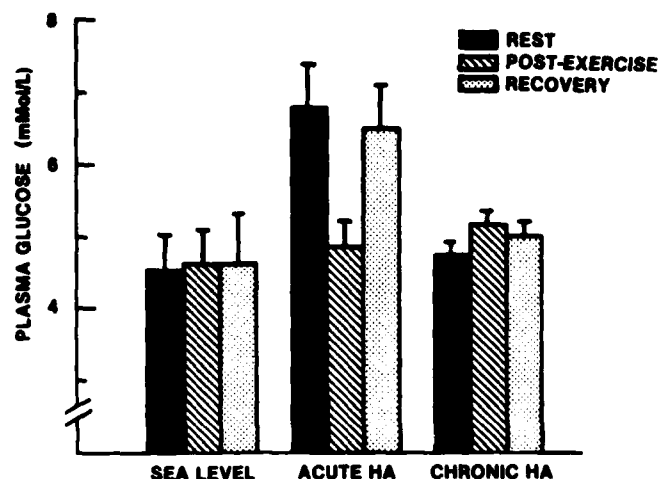


FIG. 4. Plasma glucose levels at rest, immediately after exercise ( $t < 1$  min), and after 30 min of recovery for all test subjects ( $n = 11$ ) at sea level, acute high altitude (HA;  $t < 24$  h), and chronic HA ( $t = 13$  days). See legend to Fig. 2 for additional details.

TABLE 2. Effect of submaximal cycling exercise on FFA/glycerol molar ratio

	Before Exercise	After Exercise
Sea level	$2.98 \pm 0.81$	$1.82 \pm 0.46$
Acute HA	$3.42 \pm 0.68$	$2.51 \pm 0.38$
Chronic HA	$4.61 \pm 0.77$	$2.83 \pm 0.86^*$

Values are means  $\pm$  SE for all subjects;  $n = 11$ . HA, high altitude; acute,  $t < 24$  h; chronic,  $t = 13$  days. \*  $P < 0.05$  from before exercise.

cise at acute HA ( $t < 24$  h) compared with exercise at sea level. Plasma insulin levels were approximately two-fold higher with acute HA than sea level or chronic HA. These findings are in contrast to those of Sutton (23) in which postexercise plasma glucose was elevated and insulin was lower following acute ( $t < 3$  h) hypobaric exposure compared with sea level. In that study, the subjects exercised at the same absolute work load that was estimated to be between 30 and 50% of the sea level  $\dot{V}O_{2\max}$  at sea level and 80% of maximum sea level during acute hypoxia. It is possible that longer exposure time and exercise at the same relative exercise intensity may exert different effects. In the present study, elevated insulin with acute HA may enhance glucose uptake by the muscle during exercise.

It is possible that decreased ammonia accumulation can lead to decreased perceptions of fatigue. It has been reported that utilization of a receptor or sink for ammonia, such as aspartic acid, resulted in increased swimming endurance time in rats (5). In the present study, the sedentary subjects showed an increase in  $\dot{V}E/\dot{V}O_2$  with submaximal exercise at altitude that was not observed in the physically active group. Since ammonia accumulation during exercise is inversely correlated with prolonged endurance in rats (5) and development of exercise-induced hyperpnea (19, 21, 25), it is possible that decreased ammonia accumulation may contribute to a decrease in the perception of exercise exertion and thereby account for the reported increased endurance capacity observed with altitude acclimatization (16).

In summary, postexercise plasma ammonia concentra-

tions are decreased with acclimatization to HA compared with exercise bouts performed at the same relative intensity at sea level or acute HA. It is possible that decreased ammonia accumulation leads to enhanced performance and alterations in energy substrate utilizations that have been observed with altitude acclimatization.

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The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation.

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